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"Development of a Submillimeter-Wavelength Immersion Grating Spectrometer"

T. G. Phillips, PI, California Institute of Technology

The broad goal of this project was to develop a broadband, moderate-resolution spectrometer for submillimeter wavelengths. Our original approach was to build an immersion grating spectrometer, and as such, the first step was to identify the best material (lowest loss, highest index) for the grating medium, and to characterize its properties at the foreseen optical-bench operating temperature of 1.5 K. To this end, we put our initial efforts into upgrading an existing laboratory submillimeter Fourier transform spectrometer (Bin et al. 1999), which allowed us to carry out the requisite materials measurements. The associated cryogenic detector dewar was also redesigned and rebuilt to carry out this work. This dewar houses the 1.5 K detector and the filter wheel used in the materials characterization. Our goal was to have the beam propagate through the samples as uniformly as possible, so the optics were redesigned to allow for the samples to be traversed by a well-defined collimated beam. The optics redesign also placed the samples at an image of the aperture stop located within the FTS. After the rebuild, we moved into the testing phase.

The choice of dielectric material is based on two parameters: a high dielectric constant, necessary in order to achieve a large size reduction compared to a metallic grating operating in vacuum, and low absorption, necessary for the signal to survive a double-traversal of the medium. In addition, ease of machinability is important. Based on these criteria, germanium was selected as the best candidate material: it has a high dielectric constant (3.8), is much easier to machine than e.g. silicon, and has the potential to achieve very low transmission losses for extremely pure samples. The vital issue then becomes a determination of exactly how low the absorption in Ge can be. For a loss in traversing a medium of length 10 cm of less than 10 percent, the absorption coefficient must be less than about 0.01/cm. We first identified a vendor of ultra-pure Ge, and acquired an initial set of samples. Using our FTS, we then established that the absorption is indeed quite low, being no more than 0.009/cm across the region of interest (Benford et al. 1998; Benford 1999). Therefore suitable ultra-pure materials are available.

An optical design for the spectrometer was also arrived at which meets all of our system requirements (Benford et al. 1998; Benford 1999). It is based on a simple single off-axis paraboloid design, in which the same collimating mirror is used to collimate the beam for the grating, and to refocus the dispersed output onto a linear detector array. (The input and output beams are displaced vertically). To minimize grating rotation, we have chosen to operate the grating in high order, using 7th order for the 450 micron window, and 9th order for 350 microns. A filter on a standard filter wheel is used to select the order of interest. Such a grating should be relatively straightforward to manufacture, as the long wavelengths imply large steps. With a 10 cm deep grating, a resolution of roughly 300 km/s can then be reached. The overall design for our submillimeter grating spectrometer can be found in Benford (1999) and Benford et al. (1998). Since the detectors must operate at temperatures of approximately 100 mK, an adiabatic demagnetization refrigerator (ADR) was purchased from other funding, and tested to the requisite temperatures. This dewar is now functioning. A new detector array mount system optimized for this spectrometer, which incorporates thermal isolation and electrical preamplification, was also designed.

After the first year of the grant, the original PI, Gene Serabyn, left Caltech, and handed over the reigns of this project to Prof. Tom Phillips. At that point it was decided that a collaboration with a French group working on Fabry-Perot systems would be the quickest way to achieve a cryogenic broadband submillimeter spectrometer in a short time frame, and so the work was redirected in that direction. Benford graduated and took a postdoctoral position at Goddard Space Flight Center where he was able to continue the work on the dewar and bolometer detectors. The new, TES, detectors were chosen for this project and were integrated with the dewar and the Fabry-Perot filter from France. The resulting detection system is now completed and will be tested at the Caltech Submillimeter Observatory (CSO) in late spring of 2001.

Publications:

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